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Insect and Disease Evaluation: Trail of the 100 Giants and Quaking Aspen Campground, Sequoia National Forest/Giant Sequoia National Monument

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Abstract

Continuing tree mortality along the Trail of 100 Giants is due primarily to pest complex interactions involving a variety of insects, diseases, overstocked vegetation and periodic drought. Trees of all sizes and species (except giant sequoia) have died over the past several years and additional mortality can be expected if no management action is implemented. Standing snags pose a significant and serious problem from the standpoint of hazardous trees. Mortality at Quaking Aspen Campground was minimal but a pest complex involving dwarf mistletoe and bark and engraver beetles is a potential impact on future forest health in the campground. In addition, the Douglas fir tussock moth, a native defoliator of Douglas-fir and true firs, was found in the campground. Pest biologies are included and management options for both areas are discussed.

Background

On May 4, 2004, personnel from the Forest Health Protection office in Sonora, California and the Sequoia National Forest/Giant Sequoia National Monument met to visit two recreation sites, the Trail of 100 Giants and Quaking Aspen Campground. Those present from the Forest included: Lew Jump, Supervisor's Office; and Tom Burns, George Powell and Steve Pintek, Tule River/Hot Springs Ranger District. The purpose of this trip was to examine stand conditions and tree mortality and discuss management options.

TRAIL OF 100 GIANTS

The Trail of 100 Giants is located at an elevation of 6100 feet in the southern portion of the 570-acre Long Meadow Giant Sequoia Grove. It is the most visited grove on the Sequoia National Forest and has a one-mile paved, wheelchair accessible trail. The overstory vegetation in the grove consists of (in order of decreasing basal area) giant sequoia, white fir, incense-cedar, sugar pine, ponderosa pine and black oak. Average basal area for the entire grove is just under 380 square feet/acre. Fire suppression has prohibited the natural establishment of any giant sequoia or pine regeneration – the understory is primarily white fir and incense-cedar.

The District had identified and removed approximately 100 hazard trees (mainly snags) along the trail between 1998 and 2001. Currently 140 dead and dying trees are present. About 80% of these trees are sugar pine and white fir, with ponderosa pine, incense-cedar and black oak making up the remainder. Trees as small as 4" DHB and as large as 67" DBH comprise this population of potentially hazardous trees.

Observations:

Much of the area along the trail is densely stocked, including the encroachment of understory trees adjacent to mature giant sequoias. In many cases, specimen sequoias are barely visible from a distance because of the dense stocking. Current individual tree and small groups of mortality including all sizes of trees and species, except giant sequoia, were scattered throughout the area.

The **fir engraver** (*Scolytus ventralis*) is associated with white fir top-kill and mortality scattered throughout the area. Wood borers, probably the **roundheaded fir borer** (*Tetropium abietis*), were found in the lower bole of fir infested with the fir engraver. The **western pine beetle** (*Dendroctonus brevicomis*) was found in dead and dying ponderosa pine. Wood borers and the **red turpentine beetle** (*D. valens*) were also evident in the lower bole of western pine beetle infested ponderosa pine. Most of the sugar pine mortality involved initial attacks in the upper bole by **pine engravers** (*Ips sp.*) and attacks in the mid to lower bole by the **mountain pine beetle** (*D. ponderosae*). The red turpentine beetle was also found infesting the lower bole of mountain pine beetle attacked sugar pine. Extensive woodpeckering was observed on pines attacked by the mountain and western pine beetles. In addition, the **California five-spined ips** (*Ips paraconfusus*) was observed infesting broken-off limbs of sugar pine.

Dwarf mistletoe (*Arceuthobium sp.*) is present in sugar pine and white fir and is contributing to tree mortality. It is not distributed throughout the site, but is found in discrete pockets. This pathogen is especially severe in overstory sugar pine and is some of the worst seen in the Sierra Nevada. **Leafy mistletoe** (*Phoradendron* sp.) is scattered throughout the Trail and is typically found in the tops of overstory white fir. Severe infections of leafy mistletoe in white fir often lead to top kill in association with attacks of the fir engraver beetle. The area is high risk for **white pine blister rust** (*Cronartium ribicola*). Branch flagging and cankers were observed in the few existing understory sugar pine along the trail and also high in the crowns of dominant and codominant trees. Scattered openings in the stand had the characteristics of **annosus root disease** (*Heterobasidion annosum*), including broken snags, intact snags and more recent

mortality. The pattern of decay in stumps and the appearance of decayed wood also were typical for this root disease. No conks were found in stumps; however, the fungus was cultured from a wood sample taken from the base of a currently dying white fir sapling. Our conclusion is that root disease is viable and active on the site.

Conclusions and Prognosis

The current level of mortality is a strong indication that the Trail of 100 Giants site cannot support the amount of vegetation currently growing on it. Without management action, mortality can be expected to continue at above normal background levels. Mortality levels associated with **bark and engraver beetle** activity will fluctuate from year to year but over time, will be higher than in unmanaged stands. Periods of below normal precipitation and pest complex interactions with mistletoe, blister rust and annosus root disease, will substantially contribute to increased levels of bark and engraver beetle-related mortality. Such tree mortality will continue to create potentially hazardous conditions along the trail.

Root disease centers will remain active and continue to enlarge underground as long as hosts (giant sequoia and white fir) maintain root contacts with infected adjacent trees. Root disease in these species can cause failure of live, green trees, including specimen sequoias . There is very little sugar pine understory, but **white pine blister rust** will eventually kill most regeneration as conditions favorable for infection occur. **Dwarf mistletoe** infestations normally intensify over time – trees already infected will become more severely infected, and the pathogen will spread from infected trees to now healthy trees

Management Options

Bark and engraver beetles. Managing vegetation to promote healthy vigorously growing trees and stands is critical to reducing and preventing bark beetle-related mortality. Regulation of stocking is essential to maintain stands at stocking levels appropriate for the species and site so as to minimize between-tree competition and help reduce the susceptibility of trees to bark beetle attack. Reducing stocking levels to between 55%-70% of normal through thinning should be effective in reducing the probabilities of bark beetle-related mortality. Management of green pine slash (i.e., chipping, lop and scatter etc.) is important to reduce the potential for pine engraver populations to build-up in the slash and subsequently attack residual pines. In addition, implementing management actions designed to reduce the effects of diseases on trees and stands (see below), will also improve tree vigor and reduce the likelihood of bark beetle attack.

There is a relatively high proportion of white fir in the vicinity of the Trail of 100 Giants and there are a number of interrelated insect and disease problems associated with the fir (fir engraver, leafy and dwarf mistletoe, root disease). The fir engraver not only contributes to whole tree mortality, but also kills the branches and tops of true fir. The dead tops and branches, as well as the dead trees, can constitute hazards in heavily used recreation areas like the Trail of 100 Giants. Given these circumstances, it seems appropriate to regulate species composition by

reducing the amount of white fir in the stands and increasing the amount of both ponderosa and sugar pine.

Dwarf mistletoe: This pathogen is common in California forests and can be reduced to acceptable levels through cultural treatments. Some of the sugar pine and white fir are already so severely infected that they should be removed to protect the residual stand. Trees with less mistletoe can be successfully treated by removing infected branches and witches' brooms. Forest Health Protection provides competitive funds for the suppression of pests like dwarf mistletoe. The Tule River/Hot Springs Ranger District has been utilizing this program for the past several years and is familiar with the process of requesting funds. If the District chooses to pursue dwarf mistletoe suppression funding for the Trail of 100 Giants, FHP will provide support.

White pine blister rust: This introduced obligate parasite is especially lethal to young sugar pines. Infected overstory trees may survive even though the rust is already established in the crown. Region 5 has put a lot of effort and emphasis on identifying and utilizing sugar pine that is genetically resistant to blister rust. If opportunities arise for planting pines in stand openings along the trail, only rust resistant sugar pine should be used.

Annosus root disease: Although little can be done to stop the underground spread of established annosus root disease centers, continuing to treat the stump tops of all cut conifers with Sporax® is essential. (This treatment is Regional policy for developed recreation sites.) At present only white fir appears to be affected by this root disease, but it has the ability to spread from white fir roots to giant sequoia roots. This root pathogen has been implicated in past failures of green, mature sequoias.

QUAKING ASPEN CAMPGROUND

This 32-campsite facility is located on 22 acres at an elevation of 7000' along the Western Divide Highway (T.21S., R.32E., S.8). The overstory consists of red and white fir with a few Jeffrey pines. In general, stocking is low to moderate (< 200 sq.ft./acre) although there are some vegetation aggregations that exceed 400 sq.ft./acre. There is little to no understory throughout the campground.

Observations

No recent **bark or engraver beetle**-related tree mortality or top-kill was observed. However, five viable egg masses of the **Douglas-fir tussock moth** were found on white fir near campsite #22. The Douglas-fir tussock moth is a native defoliator of Douglas-fir and true firs. It usually occurs at low, non-damaging, population levels but periodically increases to outbreak levels. Douglas-fir tussock moth outbreaks generally last about three years and have the potential to cause significant defoliation to host trees that can result in growth loss, top-kill and mortality.

Several red fir within the campground and on its perimeter showed scattered branch flagging. The cause of this type of branch mortality is normally **Cytospora canker** in association with **dwarf mistletoe**. A dwarf mistletoe suppression project was funded by Forest Health Protection in FY 2001. At that time an estimated 76% of the red firs had Cytospora canker flagging, and the average Hawksworth dwarf mistletoe rating was 3.5. Firs with light to moderate infections were pruned to remove most of the parasite. Some severely infected trees were identified for removal but were never cut. These trees are now showing the most branch flagging. **Annosus root disease** is active in the campground and viable conks were found in one fir stump.

Conclusions and Prognosis

Although current **bark and engraver beetle**-related mortality is minimal in Quaking Aspen Campground, the potential exists for future mortality to occur as stocking levels increase due to in-growth. Dwarf mistletoe and annosus root disease increase the susceptibility of host trees to bark beetle attack. The likelihood of increased mortality will increase during periods of below normal precipitation.

Results from the 2003 **Douglas-fir tussock moth** early warning pheromone trap system, including plots on the Greenhorn RD and State lands in Tulare and Kern Counties, indicate that populations may be increasing in host areas throughout the Sierra Nevada, northern California and southern Oregon. If the Douglas-fir tussock moth increases to outbreak levels in and around the campground in the next year or two, there is a reasonably high probability that there will be significant defoliation of true fir (primarily white fir) that could result in moderate to high levels of top-kill and mortality. In addition, Douglas-fir tussock moth larvae have urticating hairs that can cause an allergic reaction in some people and thus is a potential public health problem in developed recreation and other high-use areas.

Locations with active **annosus root disease** will likely experience future tree mortality and possible windthrow. Any fir that regenerates within disease pockets will eventually be killed. Red fir with severe dwarf mistletoe infections are probable targets for bark beetle attacks. When left to run its own course, this parasite normally becomes more severe over time. Infected overstory trees will provide sources of seed that will infect smaller trees. Red fir seedlings less than 4 feet tall that regenerated naturally are already infected with mistletoe. Under current conditions, these trees will not survive to become part of the overstory.

Management Options

Bark and engraver beetles. The management options for bark and engraver beetles in Quaking Aspen Campground are essentially the same as those discussed for the Trail of 100 Giants. Stocking regulation to reduce basal area in overstocked aggregations to appropriate levels and preventing overstocked conditions from developing in other areas will reduce the potential for

future bark beetle related mortality. Similarly, implementing management actions to reduce disease impacts will reduce the probability of future bark beetle related mortality.

Douglas-fir tussock moth. As noted above, the potential for increasing Douglas-fir tussock moth populations goes well beyond Quaking Aspen Campground. Site-specific egg mass/ larval surveys will be conducted in locations throughout the range of the tussock moth in California starting in mid-June/July, 2004. These surveys will provide a better determination of where Douglas-fir tussock moth populations are increasing and where subsequent actions may be warranted. Depending on the results of these surveys, Douglas-fir tussock moth-related actions will be initiated as appropriate.

Annosus root disease: Continued use of Sporax® to treat freshly cut stump tops will prevent the start of new disease pockets. Planting pine could offset the impact of existing openings created by root disease in true fir.

Dwarf mistletoe: The District should consider requesting additional Forest Health Protection funding for a follow-up mistletoe suppression project. Some red fir not treated in the 2001 project could be pruned. Other trees are so heavily infected that they should be removed. If removal is not an option because it would create unwanted openings, pines could be planted.

PEST BIOLOGIES

Fir Engraver

The fir engraver (*Scolytus ventralis*) attacks both white and red fir in California. Trees ranging in size from large saplings to overmature sawtimber are susceptible. Attacks can cause patch-killing of cambium along the bole, top-kill, branch-kill or tree mortality. The fir engraver usually has one and sometimes two generations per year.

Adults fly and bore into trees from June to September. The adults bore through the outer bark and excavate horizontal egg galleries (across the grain) in the phloem and sapwood with larval galleries occurring at right angles to the egg galleries (with the grain). The fir engraver generally overwinters as larvae in the outer phloem. Pitch tubes are not formed as they are with pine bark beetles; the usual evidence of attack, in additon to crown fade, is reddish brown boring dust in bark crevices and spider webs along the trunk. Pitch streamers on the mid and upper bole often indicate unsuccessful attacks. Trees colonized early in the summer may begin to fade by early fall, but those colonized later in the year usually do not fade until the following spring or summer, often after the beetles have emerged.

Roundheaded Wood Borers

The roundheaded wood borers or longhorned beetles are in the Family Cerambycidae and derive their name from the fact that the adult antennae are at least half the length of the body and often as long or longer. They attack all California conifers. Most species have a life cycle of one to two years; some species require up to five years to complete a cycle. Adults lay their eggs on the bark of weakened or recently dead trees. After hatching from the eggs, larvae bore through the bark into the phloem where they feed for a few weeks to several months. Depending on the species, some will also bore into the sapwood with the potential for causing significant degrade. The larval galleries are winding and packed with frass, wood chips or both; tunnels in the sapwood are oval in cross section. The larvae are cylindrical, elongate, segmented, and white or yellowish in color, with a hardened plate on top of the first segment behind the head.

The **roundheaded fir borer**, (*Tetropium abietis*), has a one year life cycle and attacks true firs. It is often found associated with firs attacked by the fir engraver, *Scolytus ventralis*. The roundheaded fir borer can attack and kill fir weakened by severe drought or root disease.

Western Pine Beetle

The western pine beetle, (*Dendroctonus brevicomis*), breeds in the main bole of living ponderosa and Coulter pine larger than about 4 inches dbh. It often attacks trees weakened by drought, overstocking, root disease, dwarf mistletoe or fire. Adult beetles can emerge and attack trees from spring through fall. Depending on the latitude and elevation, there can be from one to four generations per year.

In addition to crown fade, pitch tubes and red boring dust on the bole are indications of successful attacks. Adults bore through bark crevices and excavate sinuous galleries packed with frass. The female lays eggs in niches along the sides of the galleries. The larvae feed in the inner bark for a short distance and then turn into the outer bark to complete development. Bluestain fungi, introduced by adults during successful attacks, can cause discoloration of the sapwood around the galleries. Mortality can occur as individual trees, small groups or, during outbreak conditions, groups of up to 20-plus trees.

Red Turpentine Beetle

The red turpentine beetle, (*Dendroctonus valens*) occurs throughout pine forests in North America (except the southeastern part of the United States) and can probably attack all species of pine within its range. Sugar pine, ponderosa pine, lodgepole pine, Jeffrey pine and Monterey pine are common hosts in California. The red turpentine beetle is attracted to certain terpene hydrocarbons released from wounded pines and frequently attacks fire injured trees and freshly cut stumps. Ponderosa pines infected with black stain root disease are particularly susceptible to attack and red turpentine beetle attacks may be an indicator of the presence of the disease. Trees attacked by the red turpentine beetle do not necessarily die but may be predisposed to attack by more aggressive bark beetles like the western and mountain pine beetles.

Depending on latitude and elevation, the red turpentine beetle can complete from three generations in one year to one generation every two years. Adult flight usually occurs between May and October although in the warmer parts of its range it can fly at any time. Attacks usually occur in the basal section of the bole within 6 to 12 inches of the ground, often at the soil line or root crown and are characterized by large, reddish, pitch tubes near the point of entry. On severely stressed trees attacks may extend underground on the main roots up to 15 feet from the bole and extend up the bole to a height of 12 feet or more.

Adults average about 8 mm in length and are generally considered to be the largest of the western bark beetles. Adults excavate long, vertical, egg galleries in the cambium. The female lays eggs along the sides of the gallery in groups of up to 100 eggs that are loosely packed with frass. The larvae often feed as a group rather than in individual, discrete, larval galleries. Both larvae and adults overwinter.

Pine Engravers

Pine engravers, (*Ips* spp.), have been recorded from most species of pines in California. Pine engravers commonly cause top-kill to pines of all sizes and mortality to saplings, poles. Under drought or outbreak conditions, they can cause mortality to trees up to 26 inches DBH. Pine engravers can also attack and breed in fresh slash resulting from logging operations as well as broken tops and limbs due to wind and snow breakage. Evidence of attack, in addition to top-kill or crown fade, include small pitch tubes and reddish boring dust in bark crevices. Attacks on slash are indicated by piles of boring dust on the bark surface and on the ground beneth the slash.

Adult pine engravers are characterized by having the rear of the wing covers scoped out forming the posterior declivity which has varying numbers of spines on the sides. Attacking males bore nuptial chambers in the inner bark and are joined by females. After mating, each female bores an individual egg gallery which lightly scores the sapwood. The size and pattern of the combined gallery pattern is often indicative of the species of *Ips* involved. The galleries are kept open by beetles pushing boring dust out through the entrance hole. Depending on the species, elevation and latitude, there can be one to several generations per year. The California five-spined ips, *I. paraconfusus*, can have from two to six generatrions per year.

Mountain Pine Beetle

The mountain pine beetle, (*Dendroctonus ponderosae*), attacks ponderosa, lodgepole, sugar and western white pines larger than about 4 inches DBH. Extensive infestations have occurred in mature lodgepole pine forests. In California, individual, large, sugar pines are often killed and group killing can occur in overstocked pine stands.

The mountain pine beetle usually has one generation per year, with attacks occurring from late June into October. Two generations per year may develop at low elevations. In addition to crown fade, pitch tubes and reddish boring dust in bark crevices or spider webs on the bole indicate successful attacks. The adults bore long vertical egg galleries and lay eggs in niches along the sides of the gallery. A "J"-hook is common at the lower end of the gallery. The larvae feed in mines perpendicular to the main gallery and construct small pupal cells at the end of these mines where they pupate and transform into adults. Larvae and adults overwinter. The sapwood of successfully attacked trees can become bluestained.

Douglas-fir Tussock Moth

The Douglas-fir tussock moth, (*Orgyia pseudotsugata*), is a native defoliator of true firs and Douglas-fir in western North America. The preferred host in California is white fir although at high population levels, late-stage larvae may feed on other firs and pines. The tussock moth completes one generation per year and has four life stages: egg, larva, pupa and adult. Damage is caused by larval feeding on the foliage of the host tree. Under outbreak conditions, tusssock moth defoliation can result in tree mortality, top-kill and growth loss. In addition, the larvae have urticating hairs which can cause an allergic reaction in susceptible individuals.

The tussock moth overwinters in the egg stage in masses of a few to 350 eggs per mass deposited by females on white fir foliage, branches and/or on the trunk. Eggs are laid from August through October. The larvae emerge from the eggs in mid- to late-June the following year. Larval emergence is usually synchronized with bud break and needle expansion on the the host firs as early stage larvae can only feed on the current year's foliage; later-stage larvae can feed on older foliage. The larvae go through four to six moults, and feed on foliage into late-September and October. Pupation occurs from late- July into October, also on the foliage, branches and trunk. Adult males fly from late-July into October and November. The adult female has only rudimentary wings and does not fly. After emerging from the cocoon, female DFTM emit a sex

pheromone to attract males during the flight period, and, after mating, deposit the next generation egg masses on or near the cocoon.

Dwarf Mistletoes

Dwarf mistletoes (*Arceuthobium* spp.) are parasitic, flowering plants that can only survive on living conifers in the family Pinaceae. Each species of dwarf mistletoe infects one or a few closely related species of trees. They obtain most of their nutrients and all of their water and minerals from their conifer hosts.

Dwarf mistletoes have a unique method of seed dispersal. Seeds are forcibly discharged in the fall when the fruit ripen and are shot out for many feet. The seed is covered with a sticky substance and adheres to whatever it contacts. When a seed lands in a host tree crown, it usually sticks to a needle or twig, where it remains throughout the winter. The following spring the seed germinates and penetrates the twig at the base of the needle. For the next 2-4 years, the parasite grows within the host tissues, developing a root-like system within the inner bark and outer sapwood, and causing the twig or branch to swell. Aerial shoots then develop and bear seed in another 2-4 years.

Dispersal of dwarf mistletoe seeds is limited to the distance the seeds travel after being discharged. From overstory to understory, this is usually 20 to 60 feet, but wind may carry them as far as 100 feet from the source. A rule of thumb is that the seeds can travel a horizontal distance equal to the height of the highest plant in an infected tree. There is some evidence that long distance spread of dwarf mistletoe is occassionally vectored by birds and animals.

Vertical spread within tree crowns of most dwarf mistletoes is limited to less than one foot per year because of foliage density. Because of the thin crowns of Digger pine, however, the vertical rate of spread has been measured as being greater than 2 feet per year. This rate of spread equalled or exceeded the rate of height growth of infected trees.

Dwarf mistletoes are easy to identify because they are generally exposed to view within a tree's crown. Signs of infection include the yellow- green to orange mistletoe plants, basal cups on a branch or stem where the plants were attached, and abscised plants on the ground beneath an infected tree. Symptoms include spindle-shaped branch swellings, witches' brooms in the lower crown, and bole swellings.

True Mistletoe

True, or leafy, mistletoes are parasitic plants in the genus *Phoradendron* with mature shoots more than six inches long. The size of their shoots help to distinguish them from dwarf mistletoes. The foliage of true mistletoes may be leafy or scaly, and their fruit is a round berry. They are mainly parasites of hardwoods but also infect several species of conifers in California, and obtain water and minerals from their host.

This pest is spread mainly by birds, including robins, bluebirds, thrushes, and cedar waxwings. Birds feed on the berries, digest their pulp, and excrete the living seed, often depositing them onto susceptible trees. A viscous coating and hair-like threads on the outer surface of the seeds attach them firmly to twigs and branches, where they germinate and infect host tissues.

Young or small trees are seldom infected by true mistletoe. In nearly all cases, initial infection occurs on the branches of larger or older trees because birds prefer to perch in their tops. Severe buildup of mistletoe often occurs in an already-infected tree because birds are attracted to and may spend prolonged periods feeding on the mistletoe berries.

True mistletoes are often considered to be curiosities, but they can be serious pests where individual trees are of high value, as in yards, parks, and campgrounds. Heavily infected trees are weakened, reduced in growth rate, and sometimes killed. Weakened trees are predisposed to attacks by insects and often die during drought or other periods of stress. Branches and tree tops heavily-laden with true mistletoe often break during wind storms, increasing the hazard to people and property in campgrounds and other developed sites.

White Pine Blister Rust

Blister rust (*Cronartium ribicola*) is caused by an obligate parasite that attacks sugar and western white pines and several species of *Ribes*. The fungus needs the two alternate hosts to survive, spending part of its life on 5-needled pines and the other on *Ribes*. The disease occurs throughout the range of sugar pine to the southern Sierra Nevada, but has not been reported further south. Infection of pines results in cankers on branches and main stems, branch mortality, top kill, and tree mortality.

Spores (aeciospores) produced by the fungus in the spring on pine bole or branch cankers are wind-disseminated to *Ribes* where they infect the leaves. Spores (urediospores) produced in orange pustules on the underside of the leaves re-infect other *Ribes* throughout the summer, resulting in an intensification of the rust. A telial spore stage forms on *Ribes* leaves in the fall. Teliospores germinate in place to produce spores (sporida) which are wind-disseminated to pines and infect current year needles. Following infection, the fungus grows from the needle into the branch and forms a canker. After 2 or 3 years, spores are produced on the cankers and are spread to *Ribes* to continue the cycle. Although blister rust may spread hundreds of miles from pines to *Ribes*, its spread from *Ribes* back to pines is usually limited to a few hundred feet.

Branch cankers continue to enlarge as the fungus invades additional tissues and moves toward the bole. Branch cankers within 24 inches of the bole will eventually form bole cankers (these are called **lethal** cankers). Bole cankers result in girdling and death of the tree above the canker. Cankers whose closest margins are more than 24 inches from the main bole are unlikely to reach the bole and only branch flagging will result (these are called **non-lethal** cankers).
Environmental conditions are critical for successful infection and limit the disease in most years. Moisture and low temperatures favor infection of both hosts, and must coincide with spore dispersal for infection to occur. In California, these conditions occur only infrequently, usually in cool moist sites such as stream bottoms or around meadows. In so called "wave years" when

favorable conditions occur, high levels of infection can result. Wave years in California have occurred at approximately ten-year intervals in the past. As one moves from sites most favorable for rust to less favorable sites, the frequency of wave years decreases.

Annosus Root Disease In True Fir

Heterobasidion annosum (formerly *Fomes annosus*) is a fungus that attacks a wide variety of woody plants. All western conifer species are susceptible. Madrone and a few brush species (*Arctostaphylos* spp. and *Artemisia tridentata*) are occasional hosts, while other hardwood species are apparently not infected. The disease has been reported on all the National Forests in California, with incidence particularly high in true fir stands that have been repeatedly logged. Disease frequency tends to be higher in older stands with large fir and high basal areas (over about 330 square feet/acre).

During periods favorable to the fungus, fruiting bodies (conks) form in decayed stumps, under the bark of dead trees, or under the duff at the root collar. New infection centers begin by aerial spread of spores produced by the conks and subsequent colonization of freshly cut stump surfaces or wounds on living trees. The fungus then spreads through root contacts into the root systems of adjacent live true fir. Local spread of the fungus from a stump typically results in the formation of a disease center, with dead trees in the center and fading trees on the margin. These centers usually continue to enlarge until they reach natural barriers such as stand openings or non-susceptible plants.

In pines, *H. annosum* grows through root cambial tissue to the root crown where it girdles and kills the trees. In less resinous species such as true firs, the fungus sometimes kills trees, but more frequently it is confined to the heartwood and inner sapwood of the larger roots where it causes a chronic butt and root decay and growth loss. Thus, while infection in true fir usually does not kill the host, it does affect its growth and thriftiness. Losses in true fir from *H. annosum* are mainly the result of windthrow because of root decay, and reduced root systems that predispose trees to attack and eventual death by the fir engraver beetle. Field observations suggest that vigorous young firs are usually able to regenerate root tissues faster than they are lost to the root disease. But when true firs slow in growth because of stand and/or site conditions, root development decreases to where there is a net loss in roots and the trees slowly decline due to the gradual loss of their root systems. This decline may take 10 to 20 years before tree death occurs.

There are two pathogenic strains of the fungus that differ in their ability to infect various conifers in California. The "P" or pine type infects and kills all pines (although susceptibility of pine species vary), in addition to incense-cedar and western juniper. The "S" or fir type infects true fir, Douglas fir and giant sequoia. Knowing which type is active in a stand is important, and will allow favoring alternate conifer species because the fungus strains do not cross infect between the two groups listed above.